OPTICALLY ORIENTED CLAYS IN THIN-SECTIONS OF SOILS

by

R. BREWER

(Division of Soils, C.S.I.R.O., Canberra, A.C.T.

I. — INTRODUCTION

Within the last three or four years in Australia the study of soils by means of thin-sections has been developed as a research project and this paper is intended to review some of the conclusions and ideas that have developed particularly in regard to optically oriented clay materials in soils. The colloid materials are the most reactive part of soils and it is from the organisation of these as seen in thin-section, and more particularly of the clay mineral part of colloid material, that one can expect to glean most information concerning the genesis of soils. Several people (Frei and Cline, 1949; Cady, 1950; McCaleb, 1953) have regarded strongly optically oriented clay films and layers in B horizons as indicative of clay illuviation in soil profiles and, by and large, this conclusion seems to be valid from Australian experience. The important point, however, is the kind and degree of orientation. Thin-sections are generally 30μ thick so that if the clay "matrix" of a soil horizon is at all anisotropic under a petrographic microscope with both nicolls operative, then the clay particles must be oriented to some degree.

II. — EXPERIMENTAL

From laboratory and field data it seems that many of the clay minerals normally found in soils have a strong natural tendency to become oriented, chiefly because of the platy or elongated habit of the individual particles. Thus, many processes in soil formation, such as alternate wetting and drying, could lead to some degree of clay orientation. This characteristic is used widely in techniques such as the orientation of clay films for X-ray diffraction and it has been clearly demonstrated in this laboratory by passing dilute suspensions of natural soil clays through sand columns. In the latter experiment a clay consisting of approximately 60 percent. illite, 40 percent. kaolinite and a little quartz produced strongly oriented clay coatings on the sand grains irrespective of the dominant exchangeable cation. Similar results were obtained when sand columns were wet by capillarity with dilute suspensions of the same clay. In the field it was found that natural clays which had been dispersed by heavy rains and dried slowly in puddles formed by run-off were strongly oriented. When heavily flocculated clays are mixed with sands and silts and dried with continual stirring, strongly oriented clay films are formed if the proportion of clay to sand is low but the orientation becomes progressively weaker as the proportion of clay to sand is increased. In addition, the degree of orientation with the same proportion of clay to primary minerals decreases markedly if there is a significant percentage of silt-size material (2 to 20μ equivalent diameter) present.

These observations give a lead to the interpretation of the various phenomena of clay orientation seen in thin-sections of natural undisturbed soil profiles. It would seem that normally, if a clay has been brought into suspension, moved through the profile and then redeposited, it will produce strongly oriented clay films and coatings. On the other hand, a similar structure could be produced in an alluvial deposit where the proportion of clay to primary minerals is small and the grain-size of the primary minerals is large. In addition, deposition of heavily flocculated clays with a low proportion of primary minerals, even if they are fine grained, results in some degree of orientation sufficient to produce partial anisotropy of the clay matrix; such orientation does not necessarily indicate clay movement in soil profile genesis.

III. — CLAY ORIENTATION IN UNDISTURBED SOIL HORIZONS.

Most of the soils studied in Australia have some degree of orientation of the clay material, i.e. at least some part of the clay matrix is anisotropic. The interpretation put on this clay orientation depends on the degree and kind of orientation and in some of the cases to be cited the interpretation is supported by other measurements such as amount of mineral weathering and porosity changes down the profile.

1. *Strongly oriented clay films.* Where clay illuviation has been a significant process in the development of textural B horizons the clay is usually deposited as coatings of optically strongly oriented material. These coatings may be :

a) On primary mineral grains as in one example of a Red-brown Earth profile. This structure is not due to alluvial deposition since the parent material is a wind-blown sand. The hypothesis of clay illuviation in this profile is supported by the fact that porosity increases with depth below the top of the B horizon which indicates a filling of the pore-spaces in the upper B horizon by illuviated clay.

b) As fine bands or coatings on small or large structural aggregates as in another example of a Red-brown Earth profile. Although this profile is developed from an alluvial parent material the structure is not due to alluvial deposition. The proportion of clay to primary mineral grains is high in the B horizons of this profile and the experimental work indicates that alluvial deposition would result in a poorly oriented clay matrix such as does occur within the coated aggregates. The coatings themselves are due to clay illuviation.

c) On the walls of large pore spaces as in a Solodized Solonetz profile from Western Victoria. In this profile large amounts of clay have moved down the wide cracks between the columnar structural units of the B horizon and have been deposited as large oriented clay aggregates which show a laminated, concretionary structure with the laminae parallel to the walls of the cracks.

2. *Weathering in situ with subsequent plastic movement.* A recent study of a maximal yellow podzolic soil developed on granodiorite (Brewer, 1955) showed that most of the clay matrix is anisotropic which indicates some degree of orientation; fluidal structures (Kubiena, 1938) were observed. This kind and degree of orientation is considered to be due to alternate wetting and drying of clay formed in situ resulting in squeezing of the clay material along the faces of mineral grains. This conclusion is supported by a series of thin-sections which show progressive weathering of the primary minerals to clay minerals towards the top of the B horizon, by quantitative mineral analyses and calculations which show that mineral weathering in situ can more than account for the amount of clay in the B horizons, and by volume weight and porosity measurements which remain constant down the profile from the top of the B horizon. On the latter point, clay illuviation resulting in the development of clay films should lead to diminished porosity and increased volume weight in the illuviated horizon (Mick, 1949). The interpretation in this case is complicated by the weathering in situ of large biotite grains in the granodiorite which produce quite strongly oriented clay aggregates.

3. *Alluvial deposition with little subsequent modification.* The Grey and Brown soils of Heavy Texture have a degree of clay orientation similar to that produced by drying heavily flocculated clays with sands in the presence of significant amounts of silt-size material and where the proportion of clay to sand is high. This orientation is considered to be due primarily to the conditions of deposition of the soil parent material. Some of these soils have quite large amounts of unoriented clay material and so there has been little or no modification since deposition. Others show varying degrees of orientation up to the point where practically all of the clay matrix is anisotropic. Since none of these soils have textural A and B horizons it seems certain that the kind and degree of orientation observed is inherited from the depositional characteristics of the parent material with subsequent modification by wetting and drying processes.

4. *Clay illuviation without strong orientation.* Under certain conditions it is apparent that clay illuviation in a soil profile does not result in layers or coatings of strongly optically oriented clay aggregates. Very thick clay coatings on the faces of columnar structural aggregates in some solodized solonetz soils from Western Victoria and south-eastern South Australia show no greater degree of orientation than some of the fine-textured soils which have no development of textural B horizons. These clay coatings are obviously due to illuviation because of their position in the profile where they fill wide cracks and because in thin-section there is a sharp division between the structural units which contain about 60 percent. of primary minerals and the almost pure clay fillings. It is suggested that the formation of these coatings is analogous to the laboratory conditions where a high proportion of heavily flocculated clay was mixed with a small proportion of primary minerals. The clays have moved down in suspension into a zone of high electrolyte content, whether the salts were in the soil or in a high water table, and there flocculated and deposited without the opportunity for orientation. It is significant that four soils examined which show these characteristics come from poorly-drained sites whereas the

two which show strong orientation of the illuviated clay come from well-drained sites. This interpretation also fits in with the classification of the four poorly drained soils as solodized solonetz.

IV. — *Significance of oriented clays in the physical behaviour of soils.*

The kind and degree of orientation of the clay matrix in soil profiles has great significance in regard to the physical behaviour of the soil materials. In some recent work on finetextured soil materials (Brewer and Blackmore, 1956) the rate and degree of break-down of soil aggregates on flood wetting appears to be governed very largely by the amount of oriented clay and the degree of orientation. In fact, in soil materials with a considerable amount of strongly oriented clay layers or coatings the effects of entrapped air on aggregate break-down is quite insignificant compared with the forces developed by expansion of the oriented clays; the aggregates break down more quickly in vacuum than in the atmosphere, probably because of quicker wetting. The less the amount and degree of clay orientation the slower and less complete is the break-down of the aggregates. In addition, the size of primary aggregates into which the original aggregates break is governed by the pattern of the oriented clay coatings.

REFERENCES

BREWER R. (1955). Mineralogical examination of a yellow podzolic soil formed on granodiorite. C.S.I.R.O. Soil Pub. N° 5.

BREWER R. (1956). A petrographic study of two soils from the Murrumbidgee Irrigation Area, N.S.W. J. Soil Sci. (in press).

BREWER R., BLACKMORE A.V. (1956). The effects of optical orientation of clay on aggregate break-down and soil consistence. Aust. Y. App. Sci. (in press).

CADY J.G. (1950). Rock weatherinq and soil formation in the North Carolina piedmont region. Soil Sci. Soc. Am. Proc. 15, 337.

FREI E., CLINE M.G. 1949). Profile studies of normal soils of New York. II. Micromorphological studies of the grey-brown podzolic-brown podzolic soil sequence. Soil Sci. 68, 333.

KUBIENA W.L. (1938). " Micropedology ". (Collegiate Press, Inc., Ames-Iowa).

McCALEB S.B. (1953). Profile studies of normal soils of New York. IV. Mineralogical properties of the grey-brown—brown podzolic soil sequence. Soil Sci. 77, 319.

MICK A.H. (1949). The pedology of several profiles developed from the calcareous drift of eastern Michigan. Michigan Agr. Expt. Sta. Tech. Bul. 212.

ZUSAMMENFASSUNG

Das Studium feiner Schnitte von Bodenhorizonten und künstlich vorbereiteter Ton-Sand-Mischungen zeigen, dass allgemein die feinen, stark orientierten und kontinuierlichen Tonschichten auf den Kanalwänden und auf den elementaren Mineralkörnern das Resultat der Tonmigrierungen im Bodenprofil sind. Unter gewissen Bedingungen kann sich jedoch dieselbe Strukturenart in fluviatilen Ablagerungen oder

auch bei wechselnder Feuchtigkeit und Austrocknung im Profil bilden. Andererseits können Anschwemmungstonerden auch nicht stark orientiert sein. Aus diesem Grund sind die Beweise, die durch Porositätsmessungen und Kalkulierung der während der Bodenbildung durch Verwitterung entstandenen Tonmenge ebenso wichtig wie die Morphologie und die Profilexistenz. Es ist offensichtlich, dass die Verteilung der Tonpartikel im Verhältnis zu den Poren und elementaren Körnern in den natürlichen Bodenmaterialien einen bedeutenden Einfluss auf ihre Konsistenz und andere physikalische Eigenschaften hat.

SUMMARY

The study of thin-sections of undisturbed soil horizons and artificially prepared clay-sand mixtures indicates that, in general, strongly and continuously oriented clay films on channel walls and on primary mineral grains are the result of clay movement in the soil profile. Under special conditions, however, the same kind of fabric can be produced in the deposition of alluvia and a similar one by alternate wetting and dryings in the profile; alternatively, illuviated clays may not be strongly oriented. For this reason, supporting evidence from measurements of porosity and calculations of amount of clay produced by weathering during soil formation is valuable as are the field morphology and occurrence of the profile. It is apparent that the arrangement of the clay mineral grains with respect to the pores and primary grains in natural soil materials has a significant effect on their consistency and other physical properties.

RESUME

L'étude de sections minces d'horizons de sols en place, et de mélanges argile-sable artificiellement préparés, indique qu'en général, de minces couches d'argile fortement orientées et de manière continue, sur les parois des cavités et sur les grains minéraux élémentaires, sont le résultat du mouvement de l'argile dans les profils du sol. Sous certaines conditions, cependant, le même genre de structure peut se produire dans le dépôt des alluvions, et également par des alternances d'humection et de dessiccation dans le profil ; d'autre part, les argiles illuviales peuvent ne pas être fortement orientées. Pour cette raison, les preuves apportées par les mesures de la porosité et le calcul de la quantité d'argile produite par altération pendant la formation du sol sont importantes comme le sont la morphologie et l'existence du profil. Il est évident que la répartition des particules d'argile, par rapport aux pores et aux grains élémentaires dans les matériaux naturels du sol, a une influence significative sur leur consistance et autres propriétés physiques.